Searches for dark matter and extra dimensions with the ATLAS detector

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This paper presents the results of different approaches to finding evidence for dark matter with the ATLAS experiment at LHC. These include searches for events with large missing transverse momentum and a single jet, photon or W/Z boson. Searches for hidden sectors in events with long-lived particles resulting in displaced hadronic vertices or lepton-jet signatures are also reported. Finally, studies sensitive to the presence of extra spatial dimensions are described, as for example classical and quantum black holes and other non-resonant phenomena. Results from $\sqrt{s} = 8$ TeV ATLAS data taking are presented.

1 Dark Matter

The origin of dark matter is one of the outstanding questions in contemporary physics. Collider experiments such as ATLAS are sensitive to the pair production of so-called Weakly Interacting Massive Particles (WIMPs) in association with an initial state radiation jet, photon or W/Z, $p+p \to \chi\chi + X$, where χ denotes the WIMP and X is either a jet, photon or W/Z. The χ pair escapes the detector undetected, leading to a signature of missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$). The remaining signal characteristics are determined by the nature of X.

In the case of hadronically decaying W/Z [1], the two daughter quarks are boosted and yield a large cone jet. The large jet is reconstructed using the Cambridge-Aachen algorithm [2] of size $\Delta R = 1.2$, with transverse momentum $p_{\mathrm{T}} > 250$ GeV and $|\eta| < 1.2$. It is required that two anti-k_T jets of size $\Delta R = 0.4$ are also found inside the fat jet and that the momentum is fairly distributed between them as expected from W/Z decays, this is ensured by $\sqrt{y} = \frac{\min(p_{\mathrm{T}1}, p_{\mathrm{T}2})\Delta R_{\mathrm{jj}}}{m_{\mathrm{jet}}} > 0.4$, where m_{jet} is the invariant mass of the two small jets, and p_{T1}, p_{T2} are their momenta and ΔR_{jj} is the inter-jet distance. Finally for consistency with a W/Z decay, it is required $50 < m_{\mathrm{jet}} < 120$ GeV. A veto is applied against leptons, photons and light jets. Two signal regions are defined with $E_{\mathrm{T}}^{\mathrm{miss}} > 350$ and 500 GeV.

In the case of leptonically decaying W [3], a single electron (muon) with $p_{\mathrm{T}} > 125$ GeV (45 GeV) is required. The same lepton-dependent selection cut value is applied on the $E_{\mathrm{T}}^{\mathrm{miss}}$. The final discriminating variable is the transverse mass $m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}}(1 - \cos\phi_{\ell\nu})}$, where $\phi_{\ell\nu}$ is the distance in the azimuthal angle ϕ between the charged lepton and the direction of $E_{\mathrm{T}}^{\mathrm{miss}}$. Several signal regions are used with different thresholds on m_{T} but start to be sensitive to new physics at $m_{\mathrm{T}} > 252$ GeV.

If the associated boson is Z decaying into two charged leptons [4], the identification of the final state relies on the presence of two same flavour leptons denoted ℓ (electrons or muons), with $p_T > 20$ GeV and such that their invariant mass is within 10 GeV of the Z-boson mass, and $|\eta|$ of the dilepton system is required to be within 2.5. The dilepton system is required to balance E_T^{miss} in both direction and magnitude, with $\Delta\phi(E_T^{\text{miss}}, p_{T,\ell\ell}) > 2.5$, where $p_{T,\ell\ell}$ is the transverse momentum of the dilepton system, and $|E_T^{\text{miss}} - p_{T,\ell\ell}| < 0.5$. Several signal regions are defined by a final selection on the E_T^{miss} which ranges from 150 to 450 GeV.

The results from ATLAS dark matter searches are translated into upper limits on the WIMP-nucleon cross section as function of the WIMP mass (m_χ) in Fig. 1 using an effective field theory approach [5], in the case of spin-independent (left panel) and spin-dependent interactions (right panel).

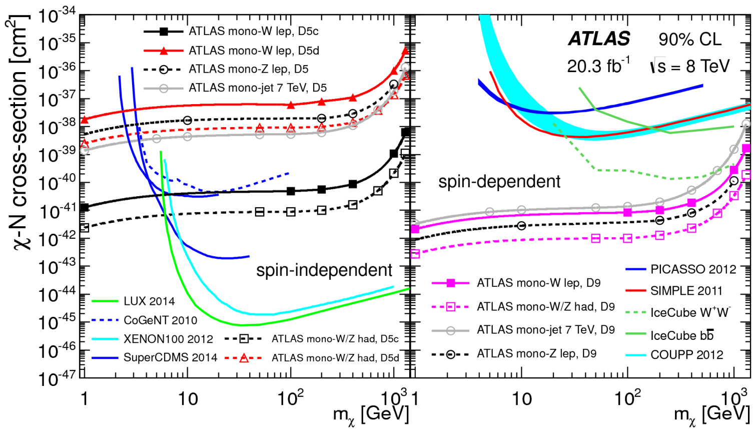

Figure 1: Summary of ATLAS upper limits on WIMP-nucleon cross section for spin-independent (spin-dependent) interactions on the left (right) panel.

2 Hidden Valley

A number of extensions of the Standard Model of particle physics (SM) involve a hidden sector that is weakly coupled to the SM, via a heavy communicator scalar particle, Φ_{HS} of mass m_Φ [6]. In the model considered here the Φ_{HS} couples to mass in the same manner as the Higgs. A confining gauge in the Hidden Sector leads to the existence of so-called valley-hadrons and include long-lived valley-pions denoted here π_v. Using a dedicated trigger that looks at the ratio of energy in the hadron calorimeter (E_{H}) to that in the electromagnetic calorimeter (E_{EM}), the ATLAS experiment looks for π_v decaying into SM hadrons deep in the electromagnetic calorimeter or inside the hadronic calorimeter [7]. The signal is searched for by selecting collisions which present two hadronic jets with $E_{\text{H}}/E_{\text{EM}} > 1.2$ and p_T of the leading jet greater than 60 GeV, and no tracks close to the jet. Standard model backgrounds are reduced by requiring E_T^{miss} <50 GeV. Figure 2 shows the resulting exclusion limits on the proper decay length of the π_v as function of its mass $m_{\pi v}$ and m_Φ.

3 Black Holes

Black holes relevant to particle physics are predicted in models with n extra dimensions. While SM particles are confined to the usual 3+1 dimensions, gravity is permitted to propagate to the extra dimensions. In this class of models the fundamental gravity scale $M_{\rm D}$ is given by $M_{\rm D}^{2+n} = M_{\rm Planck}^2 R^{-n}/8\pi$, where $M_{\rm Planck}$ is the usual Planck mass and R is the size of the extra dimensions. The fundamental gravity scale $M_{\rm D}$ could potentially be as small as a few TeV and thus requires investigation at LHC. Two types of black holes are investigated, quantum black holes (QBH), semi-classical black holes (BH).

The QBH are relevant when the black holes are produced close to their production threshold $M_{\rm th}$. In this regime the QBH decays into two high $p_{\rm T}$ particles, including lepton+quark final states that violate baryon and lepton numbers. The signal region [8] is defined by the presence of a single electron or muon with $p_{\rm T} > 130$ GeV and a jet. The final discriminating variable is the invariant mass of the lepton-jet system $M(\ell, jet)$ required to be larger than $0.9 M_{\rm th}$ in the electron channel and larger than $([0.95 - 0.05 \times M_{\rm th}]/1{\rm TeV}) \times M_{\rm th}$ in the muon channel.

The semi-classical approximation of thermal black holes where the BH loses mass and angular momentum via Hawking radiation is valid if $M_{\rm th} >> M_{\rm D}$, the BH decays to a high particle multiplicity, high $p_{\rm T}$ particle final state including both leptons and hadrons. The signal region [9] is defined by requiring at least one electron or muon with $p_{\rm T} > 100$ GeV and at least two more particles with $p_{\rm T} > 100$ GeV. The final discriminating variable is the scalar sum of the $p_{\rm T}$ of all particles with $p_{\rm T} > 60$ GeV, including both leptons and jets, and denoted $\sum p_{\rm T}$. The signal region is defined by $\sum p_{\rm T} > 2000$ GeV.

Figure 3 presents a selection of the ATLAS exclusion limits on QBH (left) and semi-classical black holes (right). In the case of QBH, production thresholds of up to 5.5 TeV are excluded. In the case the semi-classical black holes n =2 to 6 extra dimensions have been investigated, two models have been considered for black hole production and decay using CHARYBDIS [10] and BLACKMAX [11]. Both rotating and non-rotating black holes have been considered. In all cases production thresholds below 5−6 TeV are excluded for $M_{\rm D}$ between 1.5−4 TeV.

Acknowledgments

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MC sample m_Φ, $m_{\pi v}$ [GeV]	excluded range 30% BR $\Phi_{\rm HS} \to \pi_{\rm v}\pi_{\rm v}$ [m]	excluded range 10% BR $\Phi_{\rm HS} \to \pi_{\rm v}\pi_{\rm v}$ [m]
126, 10	0.10 - 4.38	0.13 - 2.30
126, 25	0.27 - 10.01	0.37 - 5.12
126, 40	0.54 - 12.11	0.86 - 5.62

Figure 2: ATLAS excluded range at 95% CL for the proper decay length of the π_v for different masses $m_{\pi v}$ and m_Φ and values of the branching ratio (BR) of $\Phi_{\rm HS} \to \pi_v \pi_v$.

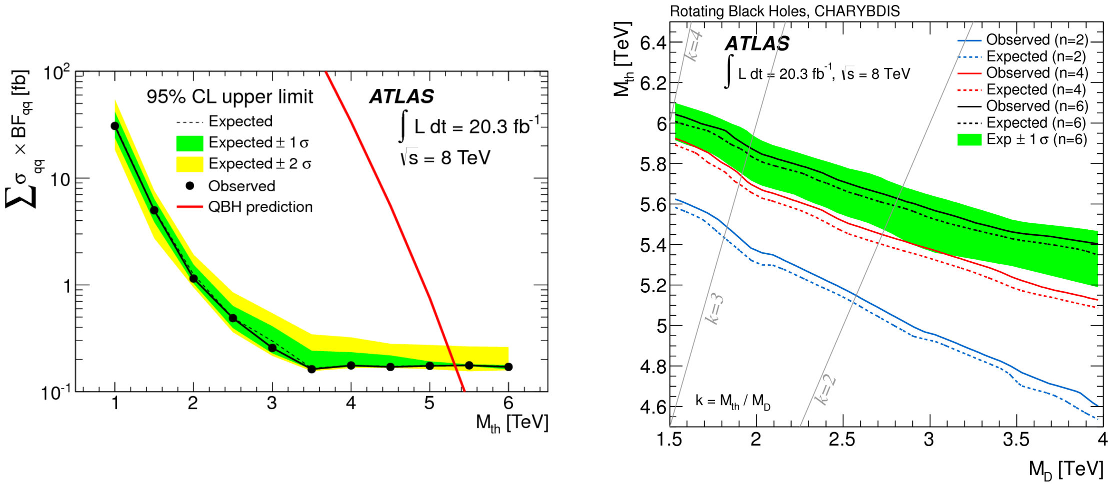

Figure 3: Left: ATLAS upper limit at 95% CL on the total quantum black hole production cross section given by the sum over all quark-quark production channels times the branching ratio of each channel into the quark+lepton final state, as function of the production threshold $M_{\rm th}$. Right: ATLAS excluded region in the case of semi-classical black holes, in the plane $M_{\rm D}, M_{\rm th}$, reproduced here in the scenario of rotating black holes simulated with CHARYBDIS.

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